1962

DEPARTMENT OF AGRICULTURE AND FISHERIES
FOR SCOTLAND

Marine Research
1962 No. 1

Herring Rearing - IV
Rearing beyond the Yolk-Sac Stage

By J. H. S. BLAXTER, M.A.
Marine Laboratory, Aberdeen

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE
PRICE 6*s.* 6*d.* NET

The following list shows the publications during recent years in the Marine Research series formerly issued by the Scottish Home Department. Details of earlier publications will be supplied on request by the Marine Laboratory, Department of Agriculture and Fisheries for Scotland, Victoria Road, Torry, Aberdeen.

MARINE RESEARCH SERIES

1959

1. Hydrography of the North-Western Approaches to the British Isles.
   By D. S. Tulloch, B.Sc., and J. B. Tait, D.Sc., Ph.D., F.R.S.E. Price 10s. (10s. 4d.)
2. Hydrography of Scottish Coastal Waters.
   By R. E. Craig, B.Sc. Price 10s. (10s. 4d.)
3. The Planktonic Stages of the Haddock in Scottish Waters.
   By Alan Saville, B.Sc. Price 7s. 6d. (7s. 10d.)
4. Halibut—Observations on its size at First Maturity, Sex Ratio and length/weight Relationship.
   By Bennet B. Rae, M.A., B.Sc., Ph.D. Price 7s. 6d. (7s. 10d.)

1960

1. The Herring of the Clyde Estuary.
   By Henry Wood, M.A., Ph.D., F.R.S.E. Price 8s. 6d. (8s. 10d.)
2. Seals and Scottish Fisheries.
   By Bennet B. Rae, M.A., B.Sc., Ph.D. Price 15s. (15s. 5d.)
3. The Scottish Seine Net Fishery, 1921-1957.
   By A. Ritchie, O.B.E., B.Sc., Ph.D., F.R.S.E. Price £1 1s. (£1 1s. 6d.)

1961

1. Trawl Performance—A Study Relating Models to Commercial Trawls.
   By W. Dickson, B.Sc. Price 18s. (18s. 5d.)
2. The Assessment of the Long Term Effects of Changes in Gear Selectivity and Fishing Effort.
   By R. Jones. Price 10s. (10s. 4d.)
3. Scottish Oyster Investigations, 1946-1958.
   By R. H. Millar, Ph.D., F.R.S.E. Price £1 2s. 6d. (£1 3s. 0d.)
4. The Oceanic and Bathypelagic Plankton of the North-East Atlantic and its possible significance to Fisheries.
   By J. H. Fraser, D.Sc., Ph.D., F.R.S.E. Price 16s. (16s. 5d.)
5. The Histological Changes in the Gonad associated with the Reproductive Cycle of the Herring (*Clupea harengus* L.).
   By A. B. Bowers, B.Sc., and F. G. T. Holliday, B.Sc. Price 16s. (16s. 5d.)
6. The Environment of a Herring Fishery.
   By John H. Steele, B.Sc. Price 6s. (6s. 4d.)

(Prices in brackets include postage)

Obtainable from Her Majesty's Stationery Office
at the addresses on page 4 of cover or through any bookseller

DEPARTMENT OF AGRICULTURE AND FISHERIES
FOR SCOTLAND

MARINE RESEARCH

1962 No. 1

Herring Rearing - IV
Rearing Beyond the Yolk-Sac Stage

By J. H. S. BLAXTER, M.A.
Marine Laboratory, Aberdeen — June, 1961

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE
1962

CONTENTS

	Page
INTRODUCTION	3
METHODS AND RESULTS	3
General	3
Survival of Larvae under Different Conditions	4
Type of tank	5
Water supply	5
Illumination	5
Temperature	6
Egg density	6
Feeding	8
Mortality	9
Behaviour and Physiological Experiments, etc.	10
Feeding behaviour	10
Speed of digestion	10
Starvation	10
Growth	12
Morphology	13
Avoidance of obstacles and perception of vibrations	13
Swimming speeds	14
DISCUSSION	15
ACKNOWLEDGEMENTS	16
SUMMARY	16
REFERENCES	17

Rearing beyond the Yolk-Sac Stage

INTRODUCTION

Failure to rear herring larvae (*Clupea harengus* L.) beyond the yolk-sac stage has been a widespread xperience (Williamson, 1909; Marshall *et al.*, 1937; Erdmann, quoted by Kotthaus, 1939; Kotthaus, 939; Jones, 1947; Hempel, 1953; Blaxter, 1957). Volodin (1956) had similar results with *Clupea harengus embras*. Survival for a limited period of time was obtained by Soleim (1942) working with *Clupea harengus* nd McMynn and Hoar (1953) and Kurata (1959) with *Clupea pallasii*. Rearing well beyond the yolk-sac age, in some cases to metamorphosis, was achieved by Meyer (1878), Schach (1939), Dannevig (1948) nd Dannevig and Hansen (1952).

Herring rearing at Aberdeen was started, not only to obtain the larvae, but also to do so under ontrolled, repeatable conditions. By this means not only could behaviour and physiological experiments e done, but also a study could be made of the effect of changes in environmental factors on the meristic naracters of the herring. Some of the earlier work has already been published (Blaxter, 1955, 1956, 1957). his paper describes some aspects of the progress of the work up to 1959. The range of the experiments as wide and the results are not entirely conclusive, but the development of a technique for rearing erring larvae beyond the yolk-sac stage is of some interest. Unfortunately no larvae reached metamorhosis in these experiments. Since 1960, however, the work has been continued at the Biologische Anstalt, Ieligoland, in conjunction with Dr. G. Hempel. Reference to this more recent work (Blaxter and Iempel, 1961; Hempel and Blaxter, 1961), in which some herring were reared to metamorphosis, is nade in footnotes.

METHODS AND RESULTS

ENERAL

Gonads were dissected from male and female herring taken from the Firth of Clyde in the spring nd from the North Sea in the autumn over the years 1957 to 1959. The gonads were stored dry in jars about 4° C for transport to the laboratory in Aberdeen. The eggs were artificially fertilised and then cubated on horizontal or vertical ground glass plates placed in tanks kept at different temperatures.

Most of the tanks used were of about 50 l. capacity (52 × 28 × 41 cm), of glass or perspex, with ack walls. In the former case the walls were painted black on their outside surfaces with bitumastic int. One large 2000 l. (120 × 120 × 120 cm) fibre glass tank was also used. This was painted with tumastic paint on its inside surface.

While various types of water supply and water circulation were tried, the main source of water was om the main aquarium supply of about 350 cu. m. This water does not go to waste but is continuously circulated through a sand filter. The temperature was maintained in the tanks by various means. he first was by mounting heating elements or cooling coils in the rearing tanks themselves (Blaxter, 56), and the second by placing some tanks in the laboratory's constant temperature room; the third ethod is shown in Fig. 1. While there was no replacement of the water in the first two methods, in hich a local circulation was produced, in the third method the water supply of the aquarium was used nd the water was, in effect, being continuously replaced. In the third method each tank had its own Sunvic" rod thermostat, encased in glass, working on the bimetal strip principle. The water first passed to an auxiliary tank where it was heated by a 125 W heater operated through the thermostat by a

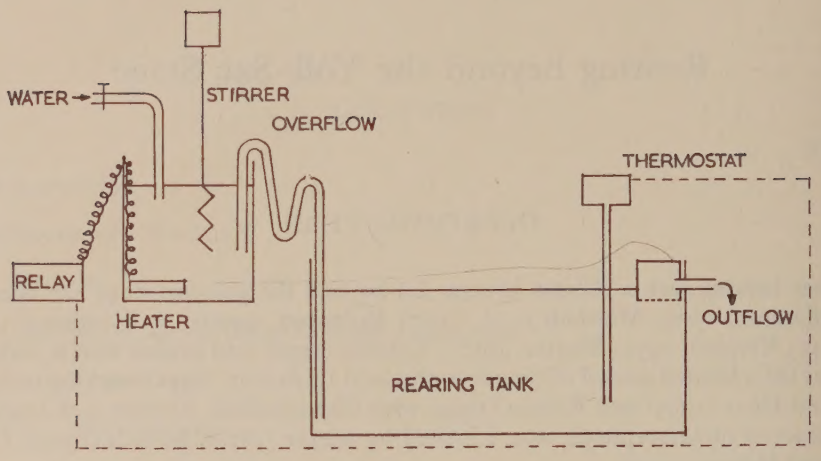

Fig. 1 Diagram of rearing apparatus.

"Sunvic" hot-wire vacuum switch. There was also a stirrer in the auxiliary tank. The water then passed through a constant-level overflow system to the bottom of the rearing tank. The water in the rearing tank flowed out through a pipe, the end of which was protected by a perspex box, the one open side of which was covered with fine black nylon gauze. This system allowed the rearing tank to be at the temperature of the main aquarium supply or at a *higher* temperature. No cooling was used.

The rate of water circulation was varied in different experiments from zero to 750 c.c./min; the usual rate of flow was about 25 c.c./min.

Observations of the salinity, pH and oxygen content of the water were made occasionally. The salinity varied from 31 to 32‰, the pH value from 8·0 to 8·2 and the oxygen content from 90 to 100% saturation.

The eggs were always incubated in darkness but, after hatching started, the tanks were illuminated by daylight, by artificial tungsten filament lamps or by banks of "daylight" strip lighting.

After hatching was completed, the plates on which the eggs had been incubated were preserved in 4% neutralised formalin for determination of percentage fertilization and hatching. This was possible because the membranes of the hatched eggs remained attached to the plates. Any samples of larvae taken or dead larvae siphoned from the bottom were also preserved in 4% formalin.

Great efforts were made to keep the tanks clean by siphoning the bottom regularly to remove dead larvae, injurious organisms, such as Stylonichidae or hydroids, and the accumulation of silt entering with the water. This accumulation was greatest when rubber tubing was used in the system and was much reduced in later experiments when plastic or glass tubing was used. Prior to siphoning the bottom of the tank was cleaned by a rubber "blade" on the end of a glass rod. One of the greatest difficulties of all was the removal of the oily scum which collected on the surface, particularly in the warmer tanks. The only satisfactory method of avoiding this was to remove the box from the outflow pipe and let the water surface itself drain off, care being taken that no larvae were lost.

Survival of Larvae under Different Conditions

Three phases of survival must be considered. The first is at hatching—the percentage hatching and health of the newly hatched larvae varied considerably under different conditions. The second phase is at the end of the yolk-sac stage when the larvae have to take food from the surrounding water. This is considered by many workers to be the critical stage in the life history of nearly all marine fish. The third phase is survival after feeding has commenced.

Type of tank

It would appear that most successful rearing to date has been achieved in rather large tanks of 2000 3000 l. (Meyer, 1878; Schach, 1939; Dannevig, 1948; Dannevig and Hansen, 1952). In the Aberdeen periments a comparison was made of survival in tanks with similar water supply and temperature ut of different capacities (2000 l. and 50 l.).

No effect of tank size on the percentage hatching was observed, but on average the percentage of atched larvae which had started to feed was about three times higher in the small tank than in the rge one. This was probably a result of the higher concentration of food in the small tank at this time, ie density of food organisms being about 5 to 10 times that in the large one.

In spring 1958 larvae lived and fed for five weeks in the 50 l. tank and eight weeks in the 2000 l. nk, although in the large tank there were few larvae left in the last few weeks. In spring 1959 the time survival was eight weeks in each tank, although growth was better in the large tank (see section on owth). In both 1958 and 1959 the larval density in the small tank was 10 to 20 times that in the large ie, the food density being higher by 5 to 10 times.

This evidence suggests that a small tank is beneficial for initial survival beyond the yolk-sac stage, hen the larvae become dependent on external sources of food, because it is easier to obtain a higher ncentration of food. Later survival did not appear to differ so much between the two tanks despite e lower concentration of food in the large tank. It seems that in the latter the food was put to "better" e; the larvae had more room to move and appeared to spend less time either turning away from the alls or swimming continuously into them. This would also explain the better growth observed in the rge tank. Perhaps the most satisfactory condition for rearing would be to keep the larvae in small nks until they started feeding and then to transfer them to larger tanks for subsequent development.*

Water supply

As far as is known all successful and even partially successful rearing of herring to date has been ne with continuously replaced sea water, shortly after it was pumped from the sea.†

When the Aberdeen rearing experiments were changed from the closed circulation system to the ntinuous replacement system in 1956 better results were obtained. Before 1956, while no effect was served on percentage hatching, from 50 to 90% of the larvae were deformed, with curved backs; terwards such larvae were rare.

Illumination

Successful rearing by other workers appears to have been done in daylight. Soleim (1942), however, ggested the importance of having an even illumination over the surface of the tank when using artificial ht. Qasim (1955) has suggested that fish larvae may need a period of sleep for optimum survival, hile Bhattacharyya (1957) and Kurata (1959) found a diurnal feeding rhythm in the larvae of *Clupea rengus* and *Clupea pallasii* respectively.

In the Aberdeen experiments artificial light has been used to a much greater extent than daylight. itially, 40 or 60 W tungsten filament bulbs were placed over the tanks on the completion of hatching, t the larvae never survived beyond the yolk-sac stage. When "daylight" strip lighting was placed in ank over the tanks, however, giving even illumination over the surface, success was at once obtained th feeding and larvae started to survive the end of the yolk-sac stage. The even illumination ensured at the food organisms were well spread throughout the tank. Feeding took place in light intensities tween 100 and 1500 photopic lux. The light was usually switched off from 2000 to 0400 hours each y by means of a time switch. Even when the lights were kept on continuously, however, no harmful ect was evident.

*In the later Heligoland experiments some larvae were reared to metamorphosis in 120 l. tanks (Blaxter and Hempel, 1961). They e not so concentrated as in the small tanks used in the Aberdeen experiments.

† Also on Heligoland in 1960.

Temperature

Blaxter (1956) showed that percentage hatching tended to be low in spring-spawned eggs at high temperatures. This has been confirmed since 1956 and further results from later experiments are given in Fig. 2. A general fall occurs in the percentage hatching of spring-spawned eggs incubated at high temperatures. On the other hand the percentage hatching seems to rise at higher temperatures up to 11 to 12° C in autumn-spawned eggs.

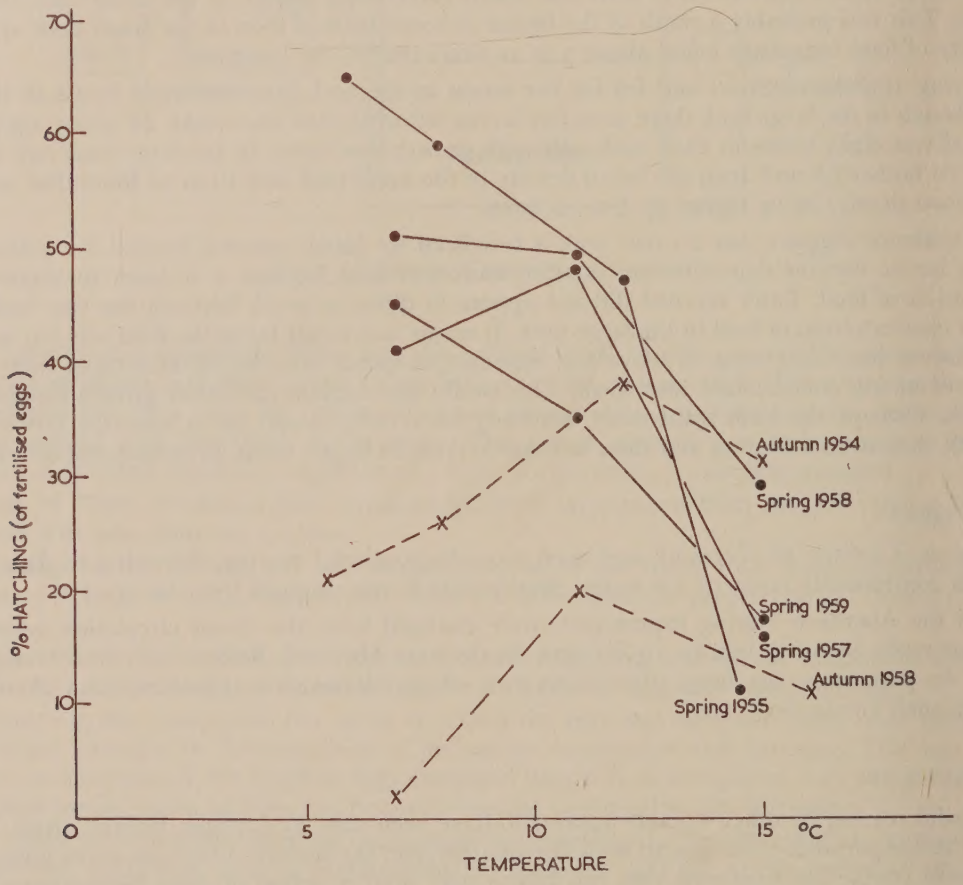

Fig. 2 The effect of incubation temperature on percentage hatching.

The effect of temperature on survival during and after the yolk-sac stage, once hatching was completed, was not easy to analyse. In the spring there tended to be fewer larvae at the higher temperature at the start of an experiment because the percentage hatching was lower. By plotting the percentage survival as in Fig. 3, no obviously harmful effect of any particular temperature up to 15° C was apparent after hatching. While growth appeared to be greater initially in the warmer tanks (see section on growth), partly owing to the larvae hatching earlier in the warmer temperatures, later growth appeared better at lower temperatures.

Egg density

Lea (1930) and Runnström (1941) have shown that overcrowding of herring eggs in the sea resulted in a high mortality after fertilization. Parrish *et al.* (1959), however, found no apparent mortality of

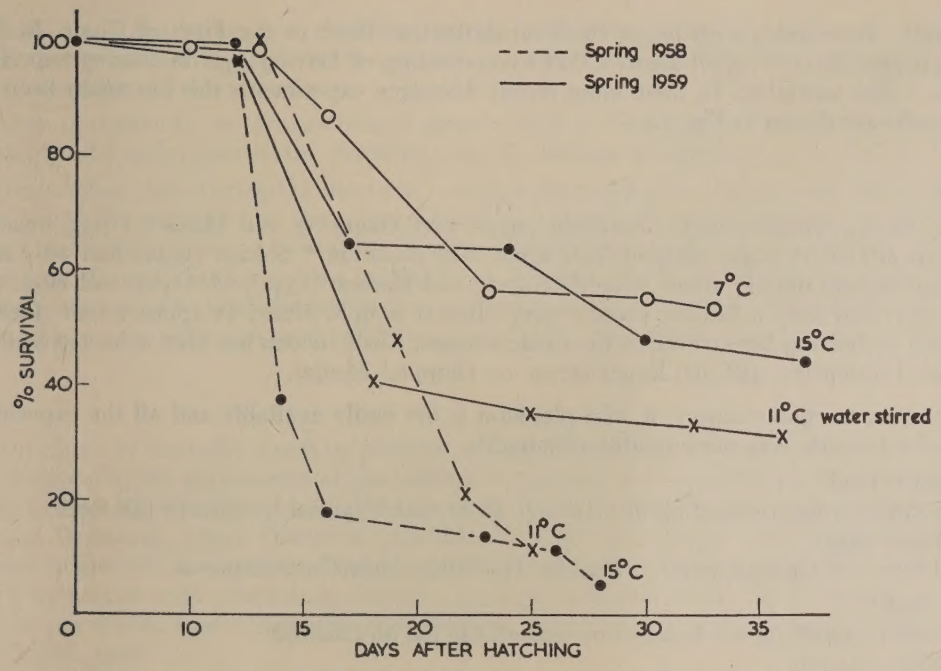

Fig. 3 The effect of temperature on survival.

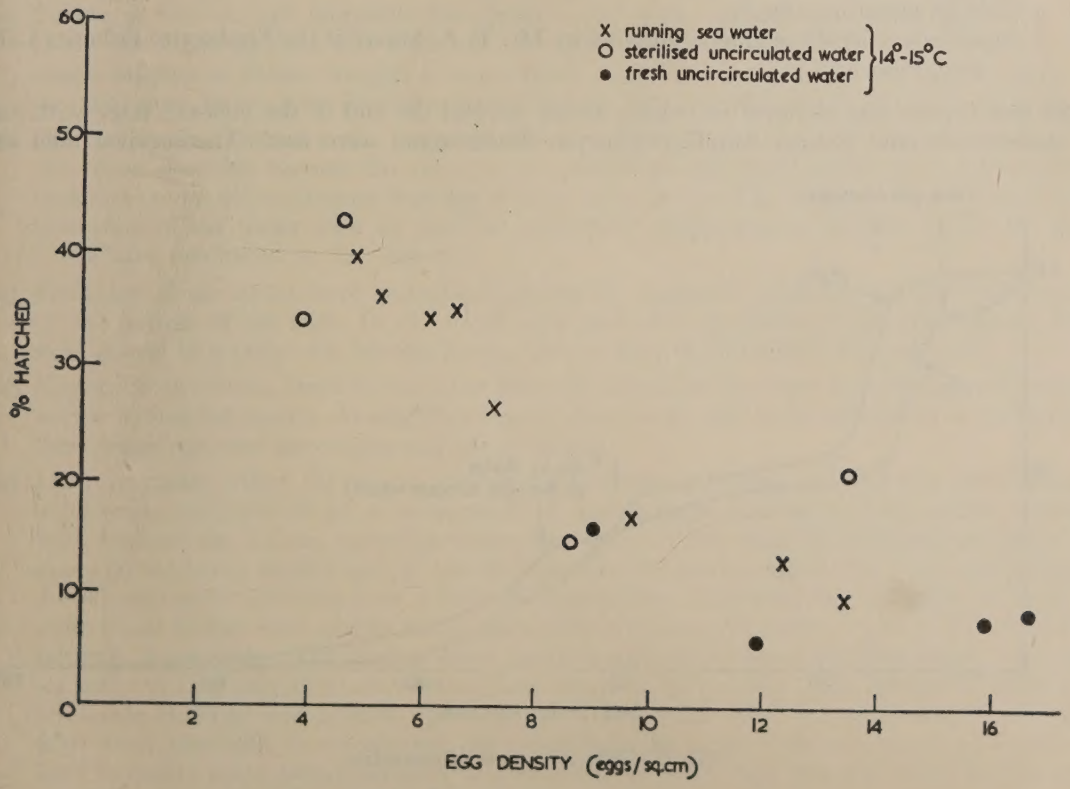

Fig. 4 The effect of crowding eggs on mortality.

eggs naturally deposited 4 to 8 layers thick on Ballantrae Bank in the Firth of Clyde. McMynn and Hoar (1953) and Blaxter (1956) showed that overcrowding of herring eggs in rearing experiments also resulted in a high mortality. In these more recent Aberdeen experiments this has again been confirmed and the results are shown in Fig. 4.

Feeding

Meyer (1878), Schach (1939), Dannevig (1948) and Dannevig and Hansen (1952) reared herring larvae to an advanced stage using at least some wild plankton.* Soleim (1942) had only a restricted success using *Balanus* nauplii alone, while Dannevig and Hansen (1952), McMynn and Hoar (1953) and Kurata (1959) had only a limited success using *Artemia* nauplii alone. It appears that *Artemia* nauplii will be taken by herring larvae even in the earliest stages. Little success has been achieved with inanimate food though Dannevig (1948) fed larger larvae on chopped *Mytilus*.

In Aberdeen a regular supply of wild plankton is not easily available and all the experiments were done with food which was more readily obtainable, i.e.:

Non-motile food:

Proprietary fish foods: Liquifry, Infusyl, Hykroflakes (ground), Spratt's fish food.
Asterias eggs.
Cultures of *Chlamydomonas, Nitzschia, Dunaliella, Chlorella, Skeletonema.*

Motile food:

Artemia nauplii (newly hatched or secondarily fed on *Chlorella*).
Balanus nauplii.
Tigriopus (young stages obtained from rock pools).
Tisbe (in aquarium supply).
Anguillicula (a small nematode supplied by Mr. T. A. Stuart of the Freshwater Fisheries Laboratory, Pitlochry).

No real success was obtained in rearing larvae beyond the end of the yolk-sac stage with any of the above foods until *Balanus* nauplii (with even illumination) were used. The survival then varied

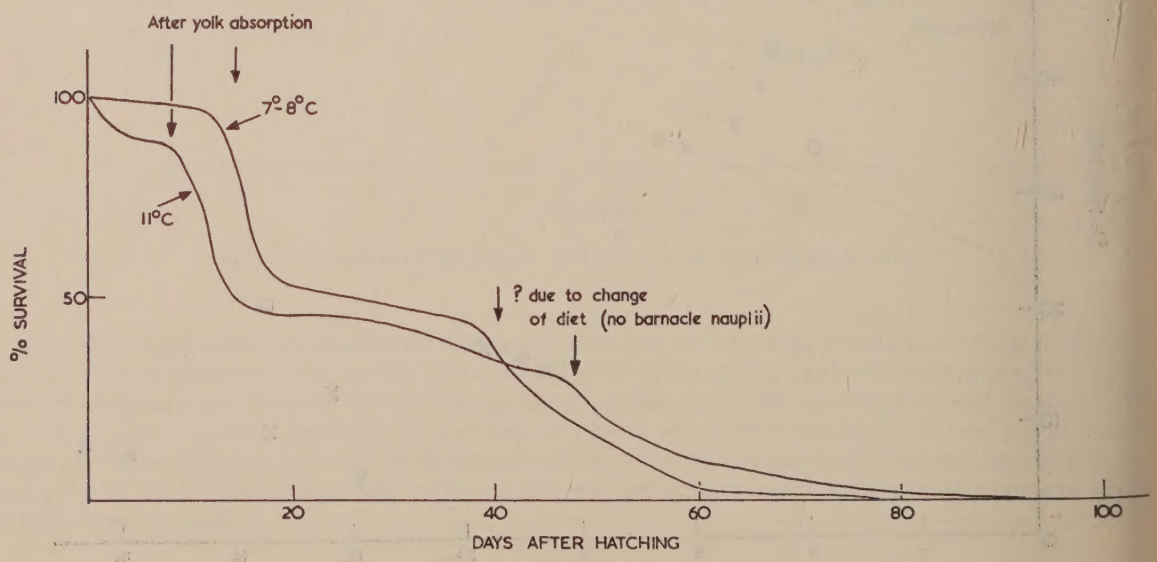

Fig. 5 Different stages of mortality.

*Wild plankton was also used in the 1960 experiments on Heligoland (Blaxter and Hempel, 1961).

m 10 to 50% and the subsequent mortality was low. However, *Balanus* nauplii were only available m mid-February until mid-April, for the nauplii are obtained by teasing the egg masses from adult *lanus* just before the spawning season.

It was then necessary to use *Artemia* nauplii alone as a food. The larvae took this organism well, but ere appeared to be an increase in the mortality rate, for instance in spring 1957 (see Fig. 5).

It is possible that this accelerated mortality would have happened anyhow and that it arose from ne other cause; for example the larvae may have been passing through a certain sensitive develop- ntal stage (see later section on mortality). Another possible explanation is that *Artemia* nauplii alone ıy not be a satisfactory diet for herring larvae. In an attempt to improve *Artemia* as a diet, the nauplii re fed with cultures of *Chlorella* before feeding to the larvae, but no improved survival was observed. ry fresh *Artemia* eggs were also used to obtain the nauplii, but with no more success.

Mortality

The main causes of mortality found by previous workers seem to have been firstly, failure of the larvae feed, and secondly, the appearance of gas bubbles in the intestine—a condition known as gas disease. is disease has already been found by Kotthaus (1939), Schach (1939), Soleim (1942), Dannevig (1948), nnevig and Dannevig (1950), Dannevig and Hansen (1952), and Blaxter and Hempel (1961). Death s also been attributed to 'predation' by hypotrichous ciliates (Kotthaus, 1939), to becoming caught lacerated by a glass wool substratum (Schach, 1939), to attacks, possibly by *Lentospora cerebralis,* and the use of unsuitable food (Dannevig and Hansen, 1952), and to being sucked against the water tflow (Schach, 1939).

In the Aberdeen experiments the causes of mortality were as follows:

(*a*) Failure to feed. A high mortality was always found at the end of the yolk-sac stage. The dead larvae contained no food and it may be assumed that they had starved to death. Even when ample supplies of *Balanus* nauplii were available, mortality was sometimes as high as 50%. The fact that some larvae were feeding suggests that the light intensity and water were suitable.

(*b*) Gas disease. In contrast to the experiences of other workers little trouble was experienced from this cause, probably because the aquarium circulation system was dependent on a large reservoir tank and not on the continuous drawing of water from the sea. This no doubt prevented the super- saturation of the water with air and the subsequent appearance of bubbles which the larvae could have swallowed at the surface.

(*c*) Predation. Some larvae were undoubtedly killed by a hydroid *Coryne* sp. which sometimes grew on the bottom of the tank. In one experiment some live specimens of the chaetognath *Sagitta* were placed in a tank with herring larvae, but no signs of predation were observed.

(*d*) Hypotrichous ciliates. Dead larvae taken from the bottom of the tanks were often heavily infested with a stylonichid species. As moribund larvae were never seen to be infested, it is assumed that these organisms were scavengers and not predators.

(*e*) Later mortality. After the initial critical post-yolk-sac mortality, survival was often good for some weeks until the larvae, at a length of 15 mm or more, had to be given mainly *Artemia* as food, because the *Balanus* spawning season was over. At this stage the mortality increased and many larvae had a swollen gut. It was thought that the larvae might have been overfeeding on *Artemia* and were suffering from a form of constipation. Following the technique of aquarists, some sickly larvae were put in tanks containing a solution of either 0·5 or 2·0% magnesium sulphate in sea water. This had no effect on their survival. Other unhealthy larvae were put in sea water of 15‰ salinity to see whether there was an osmotic upset (15‰ being near the isotonic level—see Holliday and Blaxter, 1960), but without result. Other unhealthy larvae were given algal food, *Dunaliella,* to see whether this would help but again there was no effect. Despite this later mortality many larvae survived to a length of 22 to 25 mm, and one individual reached a length of 33 mm. No larvae survived to metamorphosis.

Behaviour and Physiological Experiments, etc.

Feeding behaviour

This has been described in rearing experiments by Schach (1939), Soleim (1942), and Bückmann *et al* (1953). Meyer (1878) reported herring larvae with as many as 20 organisms in the gut, while Kurata (1959) most usually found 4 to 9 organisms in the larvae of *Clupea pallasii*. The feeding of herring larvae at sea has been extensively studied (for literature see Bowers and Williamson, 1951; Bhattacharyya 1957). The size of the food seems to increase with the size of the larvae, and a selection seems to take place as some organisms abundant in the plankton are not utilised.

In the Aberdeen experiments an S-shaped flexing of the body, followed by a rapid forward darting movement to engulf the prey, in this instance *Balanus* and *Artemia* nauplii, was observed, as described by previous authors. This behaviour pattern, which was not observed in newly hatched larvae, gradually developed during the yolk-sac stage. After studying larvae at the end of the yolk-sac stage it was estimated that 75 to 90% of these movements were abortive from the point of view of obtaining food. Once the food had been swallowed it passed in a few seconds to the end of the gut where digestion took place. Individual larvae were seen with up to 10 organisms in the gut within a few minutes of being fed. The food in the tanks was noticeably reduced about one hour after feeding time, and nauplii were rarely seen 24 hours after feeding, just before the next day's food supply was given.

In a series of experiments, larvae, 10 to 12 mm long, were given a choice of *Balanus* or *Artemia* nauplii. The average dimensions of the nauplii were:

	Length (mm).	Width (mm)	Width with arms extended (mm)
Balanus	0·3	0·25	0·5
Artemia	0·4	0·35	0·6

It was easy to see which organisms had been taken, because *Balanus* showed up white in the gut and *Artemia* orange. There was no evidence of one being taken in preference to the other.

Speed of digestion

Kurata (1959) obtained some results in rearing experiments on *Clupea pallasii*, the time for the gut contents to become transparent varying from seven to eight hours at about 9°C, and the gut emptying in 12 to 20 hours.*

In the Aberdeen experiments rates of digestion were measured by feeding larvae (usually 10 to 12 mm long) and removing them by pipette to tanks of water with no food. The approximate time for the gut contents to become transparent was then observed. The time for digestion decreased with rising temperature, see Fig. 6.

Starvation

Nothing seems to be known of how long herring larvae can survive without food, though this is obviously of some importance when trying to assess the chances of survival of larvae in the sea in different concentrations of food organisms. Nishimura (1957) reported on the amount of food taken by sardine larvae while Nikitinskaia (1958) recorded that larvae of *Clupea pallasii* require a food concentration of 20-50 mg/m^3.

Aberdeen larvae were fed with *Balanus* or *Artemia* nauplii, usually a fixed number of five organisms, and then transferred to tanks in darkness with no food. The survival time for larvae of a length of 10 to 12 mm fed on either *Balanus* or *Artemia* nauplii at different temperatures is shown on Fig. 7. It will be seen that the larvae survived longest on *Artemia*, even for as long as nine days, and there was a tendency for survival time to be shorter at the higher temperatures.

*On Heligoland (Blaxter and Hempel, 1961) digestion times of 4-6 hours were found in *Clupea harengus* larvae at 10-12° C, the time being somewhat shorter in the larger larvae.

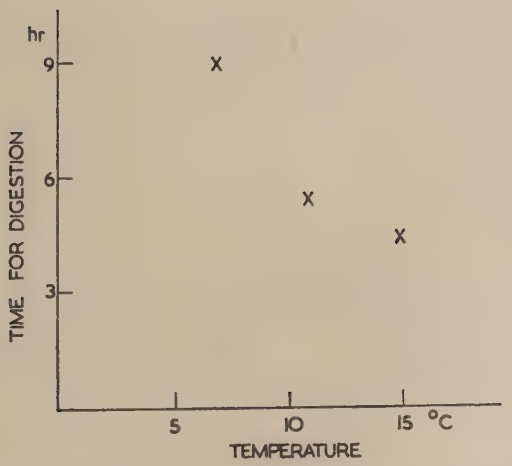

Fig. 6 The effect of temperature on time for digestion.

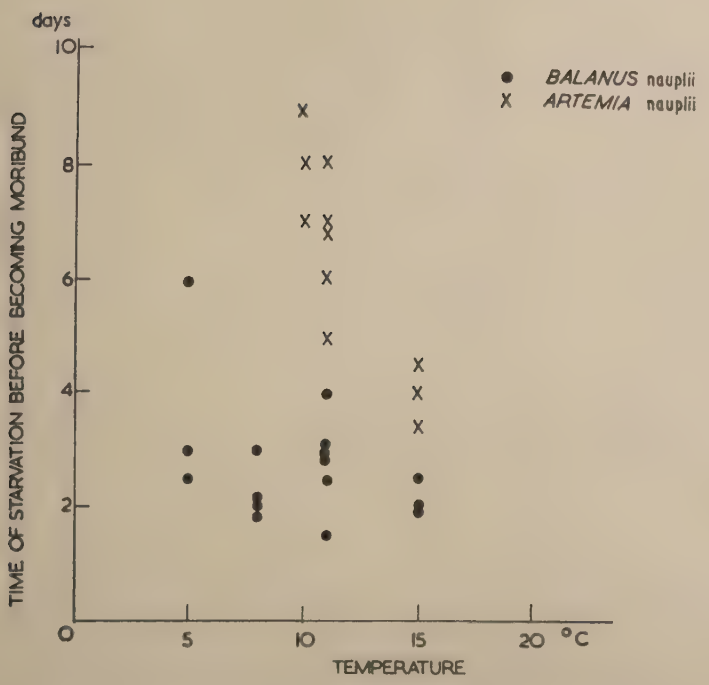

Fig. 7 The time for starvation under different conditions.

Growth

Meyer (1878) and Schach (1939), using wild plankton, obtained growth of larvae in their tank comparable with that in the sea.*

The most marked result of the Aberdeen experiments (which were successful from 1957 onwards i rearing larvae beyond the yolk-sac stage) was the great size range of larvae reared in the same condition and coming from the same parents. In 1957, in one tank maintained at a temperature of 15° C, the large larva measured 30 mm and the smallest 12 mm, but there was always more than adequate food in th tank. In general, the average growth was poorer than in the sea, but wild plankton was not used.

The size of the larvae in the tanks was measured either by sucking them into a graduated pipet or by placing a graduated glass rod alongside them in the water. The growth at different temperatur in tanks of different sizes in spring 1959 is shown in Fig. 8.

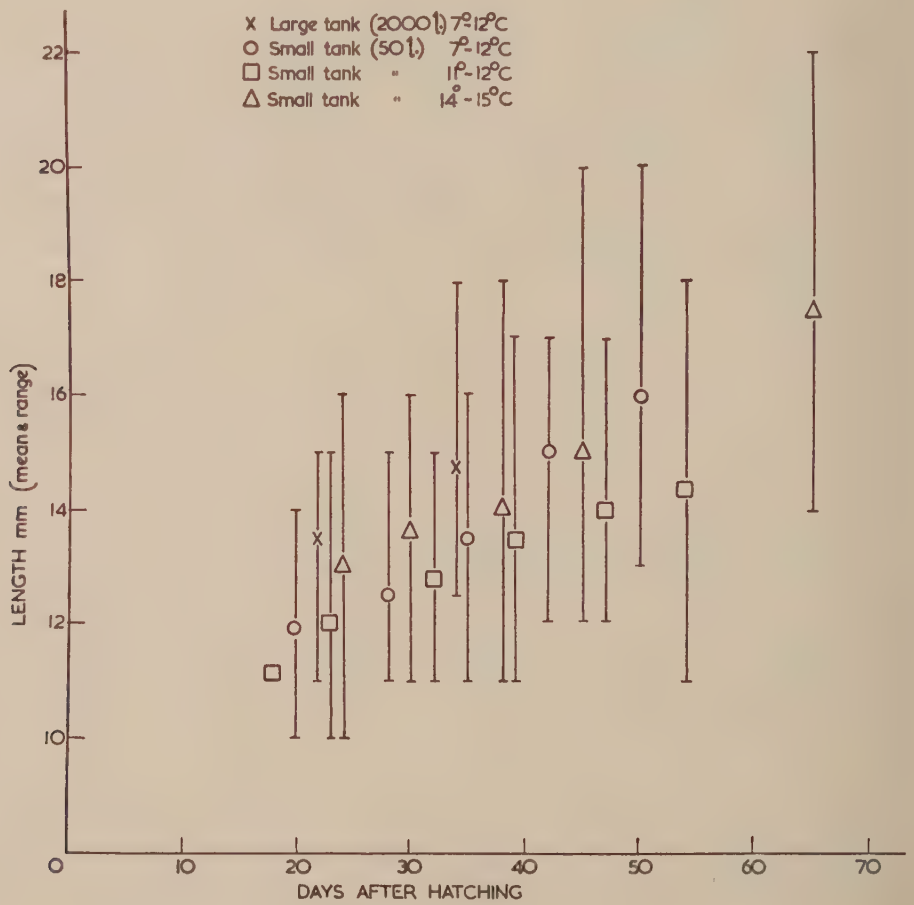

Fig. 8 Growth at different temperatures in different tanks.

There was some evidence that growth was apparently better at a high temperature. This was part due to earlier hatching which gave these larvae a start. The larvae hatched at lower temperature though hatching later, grew fast enough to overtake them. Growth seemed to be better in a large tan

*Blaxter and Hempel (1961) using *Artemia* and wild plankton also obtained good growth of some larvae, but there was a very wi size range in any one tank where the larvae were of the same origin and had been kept under the same conditions.

Morphology

While considerable work has been done on the morphology of young herring obtained from the for instance Harder, 1954; Lebour, 1921), Schnakenbeck (1929), Ramanujam (1929—quoted by n, 1940), and Gwyn (1940) worked in particular on the development of the skeleton.

n the Aberdeen experiments, on Clyde spring-spawners, samples of larvae were stained by alizarin, g Tåning's (1942) technique. The length range of the various developmental stages is shown in e I.*

TABLE I

DEVELOPMENTAL STAGES OF ARTIFICIALLY REARED CLYDE SPRING-SPAWNING HERRING

Estimated natural length (mm) (a shrinkage of about 10% has been allowed for)	Stage
6– 8	Hatching, yolk sac present, lower jaw small, little pigment.
8–10	Yolk sac absorbed, jaw grows forward, mouth becomes functional, pigment spots develop along the gut.
12–13	Dorsal fin develops as part of primordial fin (no fin rays).
13–14	Dorsal fin rays develop (stainable with alizarin).
16	Anal fin develops (without rays) as part of primordial fin. Hypurals become stainable.
16–17	Primordial fin disappears, tail begins to turn up.
17·5–20	1st uroneural becomes stainable, anal fin rays become stainable.
19–22	Last haemal arch becomes stainable.
20–24	Vertebral centra start to become stainable (in centre of body).
22–24	1st urostylar centrum becomes stainable.
24	Caudal fin rays bifurcate. Entire vertebral column becomes stainable.

oidance of obstacles and perception of vibrations

is well known that larger herring larvae are not caught satisfactorily in daylight by slow-moving kton nets (Bridger, 1956).

ome experiments were carried out in spring 1959 on larvae of 8 to 10 mm, 13 to 14 mm and 18 to

cf. Blaxter and Hempel (1961)—development seems to be slightly earlier in German coastal herring.

20 mm, to study their reaction to approaching obstacles and to low frequency vibrations. The larva were approached in a light intensity of about 500 lux at different speeds with white, black or transparen rods or by black or white nets. The reaction distances so observed are given in Table II.

TABLE II

REACTION OF HERRING LARVAE TO OBSTACLES

Obstacle		Reaction distance in cm. on slow approach 5 cm/sec	medium approach 15 cm/sec	fast approach 30 cm/sec
Glass rod	Black	0–3	0–3	0–3
	White	0–3	—	0–3
	Transparent	0–3	—	0–3
Net	Black	0–3	0–3	—
	White	0–3	0–3	—

Neither small nor large larvae reacted at all strongly to these stimuli and the speed of approach als seemed unimportant. In many cases it was necessary to touch the larvae to evoke a response. Whe touched the larger larvae reacted more strongly than the small ones. While all the above experimen were done with the obstacle approaching horizontally, in a few others the obstacle came from belov This usually evoked a much earlier response—when the obstacle was 8 to 15 cm away.

The reaction to low frequency vibrations produced in the tank was tested on larvae of 12 to 20 m in the following way. A 4 cm square perspex plate (see Fig. 9) was attached eccentrically to the cro section of the spindle of a variable-speed electric motor. The motor was switched on when the larva

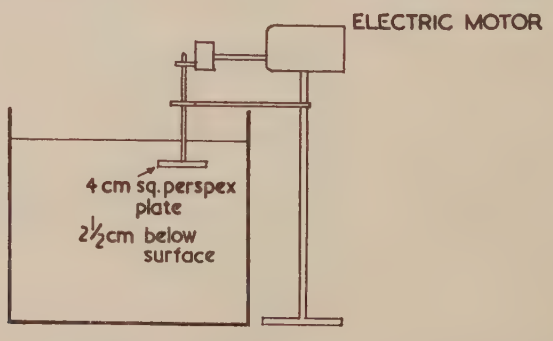

Fig. 9 The apparatus used to obtain low frequency vibrations.

were feeding or moving towards the plate. The plate then moved up and down through a distance about one centimetre at a frequency depending on the speed of rotation of the motor. This could b measured visually or by a tachometer. No reaction by any larvae was observed from frequencies of 1 t 10 cycles per second. They continued to feed or swim in the same direction.

Swimming speeds

Some data on the maximum swimming speeds of herring larvae have been given by Blaxter an Dickson (1959), the speeds ranging from 3 cm/sec for 8 mm larvae to 30 cm/sec for 20 mm larva

ıai (1960) measured the sustained swimming speed of herring larvae and found that those of 6 to 8 mm ld sustain a water current between 0·58 and 1·03 cm/sec for at least one hour.

The earlier experiments in Aberdeen were extended to cover a wider size range of larvae and a perature range of 10 to 15° C. The larvae were timed by stopwatch over measured distances in a after being touched in the caudal region with a glass rod. Two types of reaction were observed. was a steady vigorous sustained swimming away from the stimulus. The other was a "frantic" pe reaction when the larvae swam at the surface or into the walls in a completely disorientated way. average maximum speeds for a number of larvae for both types of reaction are given in Fig. 10.

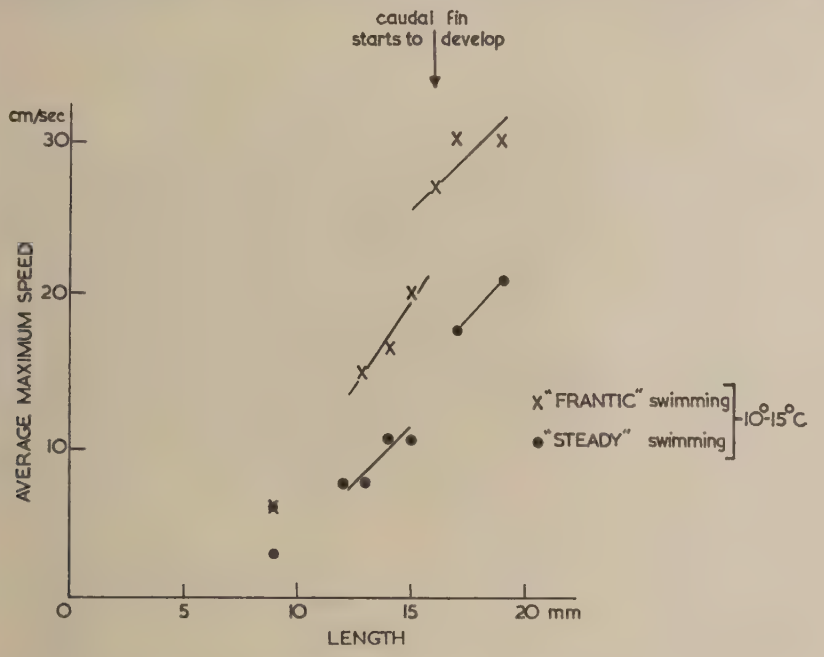

Fig. 10 The swimming speeds of herring larvae.

effect of temperature was observed and results at different temperatures are averaged. There was a lency for a sudden increase in swimming speed at a length of 15 to 16 mm, probably owing to the nation of the caudal fin at this length.

DISCUSSION

On the basis of these experiments, the following conditions may be suggested for satisfactory hatching subsequent rearing of herring larvae beyond the yolk-sac stage. During incubation the eggs should well spread out on glass plates, in tanks with a circulation of water at a suitable temperature for the icular type of herring. Though small tanks may be used for hatching and rearing to the first feeding es, those for later development should hold about 500 to 1000 l. and should be not more than 30 to m deep, otherwise they are difficult to clean. Large tanks of this size would also require a considerable l supply. *Balanus* nauplii, when available, make a good food in the early stages, but wild plankton ht be required later on, particularly if the *Balanus* supply fails. The surface of the tank should be ly illuminated to prevent the concentration of the food organisms in one place and the walls of tank should be black to give the best contrast between the food and the background.

In rearing, the critical stage occurs after the yolk-sac has been absorbed. Although Marr (1956) gested this might not be the case, it seems not unlikely that a high mortality of herring larvae also irs in the sea at this time. The high mortality in rearing experiments, where an ample supply of

food and an absence of predators would seem to suggest conditions more favourable than in the sea clearly indicates the extreme vulnerability of herring larvae. It could be that this is the time when brood strength is really determined. If this is so, small differences in the larvae, for instance, a better yolk supply or a slightly greater average size, which might tend to prolong their life, could be decisive (Bridger, 1959; Marty, 1959).*

The cause of the failure of larvae, once past the yolk-sac stage, to survive to metamorphosis, is far more difficult to decide. In the Aberdeen experiments unsuitable food might have been one cause. In most cases the tanks themselves might have been too small with resultant damage as a result of too frequent physical contact with the walls.†

ACKNOWLEDGEMENTS

Thanks are due to Dr. C. E. Lucas and Dr. G. Hempel for their valuable criticisms of this paper in manuscript, to Mr. B. B. Parrish for his advice and support during the investigations, and to Mrs. P. M. Holliday for help with the routine work.

SUMMARY

Earlier unsuccessful rearing experiments on herring larvae were continued from 1957 to 1959 with greater success. Factors such as size of tank, water supply, temperature and food were varied to see how the survival of larvae might be improved.

At first a high mortality occurred at the end of the yolk-sac stage, but this was overcome by the following means:

(*a*) the use of *Balanus* nauplii as food,

(*b*) the use of small 50 l. tanks with black walls,

(*c*) the use of running sea water,

(*d*) the use of even illumination over the surface of the tanks.

In this way large numbers of larvae survived the end of the yolk-sac stage and continued to feed and grow to a length of 15 to 20 mm. It later became necessary to use *Artemia* nauplii as food because *Balanus* nauplii were no longer available. About this time many larvae started to die and the maximum length reached was 33 mm, no larvae metamorphosing. It is suggested that by using wild plankton as food and by transferring the larvae to larger tanks this mortality might have been avoided.

The opportunity was taken to make the following observations on herring larvae from about 12 to 20 mm long—feeding behaviour and choice of food, speed of digestion, starvation time, growth and morphology, avoidance of obstacles and perception of vibrations, and swimming speeds.

*This problem is further discussed by Blaxter and Hempel (1961).

† The use of wild plankton in the later Heligoland experiments resulted in particularly good growth in the larger larvae when the plankton was not filtered. The 120 l. tanks used at Heligoland appeared to be too small for the larger larvae, which frequently swam into the walls. Despite this some larvae, in relatively low concentration, did survive to metamorphosis.

REFERENCES

HATTACHARYYA, R. N. 1957. The food and feeding habits of larval and post-larval herring in the Northern North Sea. *Mar. Res. Scot.*, 1957, no. 3, 14 pp.

SHAI, H. M. 1960. The effect of water currents on the survival and distribution of fish larvae. *J. Cons. int. Explor. Mer*, **25**, 134-146.

LAXTER, J. H. S. 1955. Herring Rearing—I. The storage of herring gametes. *Mar. Res. Scot.*, 1955, no. 3, 12 pp.

— 1956. Herring Rearing—II. The effect of temperature and other factors on development. *Mar. Res. Scot.*, 1956, no. 5, 19 pp.

— 1957. Herring Rearing—III. The effect of temperature and other factors on myotome counts. *Mar. Res. Scot.*, 1957, no. 1, 16 pp.

LAXTER, J. H. S. *and* DICKSON, W. 1959. Observations on the swimming speeds of fish. *J. Cons. int. Explor. Mer*, **24**, 472-9.

LAXTER, J. H. S. *and* HEMPEL, G. 1961. Biologische Beobachtungen bei der Aufzucht von Heringsbrut. *Helgoländ. wiss. Meeresunters.*, **7**, 260-83.

OWER A. B. *and* WILLIAMSON, D. I. 1951. Food of larval and early post-larval stages of autumn spawned herring in Manx waters. *Rep. mar. biol. Stat. Pt. Erin*, **63**, 17-26.

RIDGER, J. P. 1956. On day and night variation in catches of fish larvae. *J. Cons. int. Explor. Mer*, **22**, 42-57.

— 1959. On fecundity and larval abundance of 'Downs' herring'. Paper no. 48 given to ICES Herring Comm. Meeting, 1959.

ÜCKMANN, A., HARDER, W. *and* HEMPEL, G. 1953. Unsere Beobachtungen am Hering, *Clupea harengus* L. *Kurz. Mitt. Inst. Fischereibiol. Hamburg*, **3**, 22-42.

ANNEVIG, A. 1948. Rearing experiments at Flødevigen sea fish hatchery, 1943-46. *J. Cons. int. Explor. Mer*, **15**, 277-283.

ANNEVIG, A. *and* DANNEVIG, G. 1950. Factors affecting the survival of fish larvae. *J. Cons. int. Explor. Mer*, **16**, 211-215.

ANNEVIG, A. *and* HANSEN, S. 1952. Faktorer av betydning for fiskeeggenes og fiskeyngebens oppvekst. *Fiskeridir. Skr. Havundersøk.*, **10**, 6-16.

WYN, A. M. 1940. The development of the vertebral column of Pacific herring (*Clupea pallasii*). *J. Fish. Res. Bd Can.*, **5**, 11-22.

ARDER, W. 1954. Die Entwicklung der Respirationsorgane beim Hering (*Clupea harengus* L.). *Z. Anat EntwGesch.*, **118**, 102-123.

EMPEL, G. 1953. Die Temperaturabhängigkeit der Myomerenzahl beim Hering (*Clupea harengus* L.). *Naturwissenschaften*, **17**, 467.

EMPEL, G. *and* BLAXTER, J. H. S. 1961. The experimental modification of meristic characters in herring (*Clupea harengus* L.). *J. Cons. int. Explor. Mer*, **26**, 336-346.

OLLIDAY, F. G. T. *and* BLAXTER, J. H. S. 1960. The effects of salinity on the developing eggs and larvae of the herring. *J. mar. biol. Ass. U.K.*, **39**, 591-603.

NES, R. 1947. An artificial fertilization of herring off Laxey Bay, I. of Man. *Rep. mar. biol. Stat. Pt. Erin*, **60**, 38.

OTTHAUS, A. 1939. Zuchtversuche mit Heringslarven. *Helgoländ. wiss. Meeresunters.*, **1**, 349-358.

URATA, H. 1959. Preliminary report on the rearing of the herring larvae. *Bull. Hokkaido Reg. Fish. Res. Lab.*, **20**, 117-38.

A, E. 1930. Mortality in the tribe of Norwegian Herring. *Rapp. Cons. Explor. Mer*, **65**, 100-123.

BOUR, M. V. 1921. The larval and post-larval stages of the pilchard, sprat and herring from the Plymouth district. *J. mar. biol. Ass. U.K.*, **12**, 427-57.

cMYNN, R. G. *and* HOAR, W. S. 1953. Effects of salinity on the development of the Pacific herring. *Canad. J. Zool.*, **31**, 417-32.

ARR, J. C. 1956. The critical period in the early life history of marine fishes. *J. Cons. int. Explor. Mer*, **21**, 160-70.

MARSHALL, S. M., NICHOLLS, A. G. *and* ORR, A. P. 1937. On the growth and feeding of the larval and post-larval stages of the Clyde herring. *J. mar. biol. Ass. U.K.*, **22**, 245-67.

MARTY, Ju. Ju. 1959. Reproduction of marine herring in the light of the increasing intensity of fisheries. Paper no. 65 given to ICES Herring Committee Meeting, 1959.

MEYER, H. A. 1878. *Biologische Beobachtungen bei künstlicher Aufzucht des Herings der westlichen Ostsee.* Berlin. Wiegandt, Hempel and Parey.

NIKITINSKAIA, I. V. 1958. On the onset of active feeding of the larva of *Clupea harengus pallasii* Val. [in Russian, English summary], *Zool. Zh.*, **37**, 1568-71.

NISHIMURA, S. 1957. Some considerations regarding the amount of foods daily taken by an early post larva of sardine. *Ann. Rep. Jap. Sea Reg. Fish. Res. Lab.*, **3**, 77-84.

PARRISH, B. B., SAVILLE, A., CRAIG, R. E., BAXTER, I. G. *and* PRIESTLEY, R. 1959. Observations on herring spawning and larval distribution in the Firth of Clyde in 1958. *J. mar. biol. Ass. U.K.*, **38**, 445-453.

QASIM, S. Z. 1955. Rearing experiments on marine teleost larvae and the evidence of their need for sleep. *Nature, Lond.*, **175**, 217.

RUNNSTRÖM, S. 1941. Quantitative investigations on herring spawning and its yearly fluctuations at the West coast of Norway. *Fiskeridir. Skr. Havundersøk.*, **6**(8), 71 pp.

SCHACH, H. 1939. Die künstliche Aufzucht von *Clupea harengus*. *Helgoländ wiss. Meeresunters.*, **1**, 359-72.

SCHNAKENBECK, W. 1929. Entwicklungsgeschichtliche und morphologische Untersuchungen am Hering. *Ber. wiss. Komm. Meeresforsch.*, **5**, 23-78.

SOLEIM, P. A. 1942. Årsaker til rike og fattige årganger av Sild. *Fiskeridir. Skr. Havundersøk.*, **7**(2), 1-39.

TANING, Å. V. 1944. Experiments on meristic and other characters in fishes. *Medd. Komm. Havundersøg., Kbh.*, **11**, 1-66.

VOLODIN, V. M. 1956. Embryonic development of the autumn Baltic herring and their oxygen requirement during the course of development. *Vop. Ikht.*, **7**, 123-133. (*Fish. Res. Bd Can.* Translation no. 252).

WILLIAMSON, H. C. 1909. Experiments to show the influence of cold in retarding the development of the eggs of the herring (*Clupea harengus* L.), the plaice (*Pleuronectes platessa* L.) and the haddock (*Gadus aeglefinus* L.). *Rep. Fish. Bd Scot.*, **27**, 100-128.

Printed in Scotland under the authority of Her Majesty's Stationery Office
by Pickering & Inglis Ltd., Glasgow. Wt. 72950 K5

Other Fisheries Publications prepared by the Department of Agriculture and Fisheries for Scotland are shown below.

FRESHWATER AND SALMON FISHERIES RESEARCH

A series dealing with freshwater and salmon research under the above heading.

REPORT ON FISHERIES OF SCOTLAND

An Annual Report in narrative form containing the report of the Director of Fisheries Research and dealing generally with Scottish Fisheries, including marine superintendence, salmon fisheries and harbours.

SCOTTISH SEA FISHERIES STATISTICAL TABLES

Annual tables giving full information about the weight and value of fish landed, analysed by species, means of capture and areas of capture.

NON-SERIAL PUBLICATIONS

Lobster Storage, by H. J. Thomas . . . . . Price 1s. 9d. (1s. 11½d.)

Trout in Scotland, by K. A. Pyefinch . . . . . Price 6s. (6s. 6d.)
(A story of brown trout research at Pitlochry)

(Prices in brackets include postage)

Obtainable from Her Majesty's Stationery Office
at the addresses on page 4 of cover or through any bookseller

© *Crown copyright 1962*

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
13A Castle Street, Edinburgh 2
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

S.O. Code No. 49-38